V/f CONTROL OF INDUCTION MOTOR DRIVE

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in "Electrical Engineering"

By

Devraj Jee (109EE0039)

Nikhar Patel (109EE0087)

Under the guidance of

Prof. M. Pattnaik

Department of Electrical Engineering

National Institute of Technology

Rourkela-769008 (ODISHA)

May-2013

DEPARTMENT OF ELECTRICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

ODISHA, INDIA-769008

CERTIFICATE

This is to certify that the thesis entitled "**V/f Control of Induction Motor Drive**", submitted by **Mr. Devraj Jee (Roll No. 109EE0039), and Mr. Nikhar Patel (Roll No. 109EE0087)** in partial fulfilment of the requirements for the award of **Bachelor of Technology** in **Electrical Engineering** during session 2012-2013 at National Institute of Technology, Rourkela is a bona-fide record of research work carried out by them under my supervision and guidance.

The candidates have fulfilled all the prescribed requirements.

The Thesis which is based on candidates' own work, have not submitted elsewhere for a degree/diploma.

In my opinion, the thesis is of standard required for the award of **Bachelor of Technology degree in Electrical Engineering.**

Place: Rourkela

Dept. of Electrical Engineering
National institute of Technology
Rourkela-769008

Prof. M. Pattnaik
Supervisor

ACKNOWLEDGEMENTS

We would like to thank our project supervisor, **Prof. M. Pattnaik**, for her constant motivation and guidance during the project. We extend our heartfelt gratitude to **Prof. B. Chittibabu** for his unparalleled and timely help and support. This project could never have been completed without him. We would also like to thank all our sources, mentioned in the references, and our friends who helped us by providing mental and logistical support. Last but not the least we would like to thank our parents and God Almighty.

Devraj Jee

Nikhar Patel

B.Tech (Electrical Engineering)

National Institute of Technology, Rourkela

Dedicated to

The Department of Electrical Engineering, NIT Rourkela, for all the knowledge and wisdom imparted to us in our four years and for preparing us for our lives ahead.

ABSTRACT

This thesis presents the need of Speed Control in Induction Motors. Out of the various methods of controlling Induction motors, V/f Control has proven to be the most versatile. The overall scheme of implementing V/f control has been presented. One of the basic requirements of this scheme is the PWM Inverter. In this, PWM Inverters have been modeled and their outputs fed to the Induction Motor drives. The uncontrolled transient and steady state response of the Induction Motor has been obtained and analyzed. A MATLAB code was developed to successfully implement Open Loop V/f Control on a PWM-Inverter fed 3-phase Induction Motor, and the Torque was found to be constant for various rotor speeds. This was followed by a MATLAB model for Closed-Loop V/f Control on a PWM-Inverter fed 3-phase Induction Motor. It was observed that using a Closed-Loop scheme with a Proportional Controller gave a very superior way of controlling the speed of an Induction motor while maintaining a constant maximum torque.

Contents:

Chapter 3

PWM INVERTER

Chapter 4

V/f CONTROL OF INDUCTION MOTOR

Chapter 5

CONCLUSIONS

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

DC	-	Direct Current
AC	-	Alternating Current
IGBT	-	Insulated-Gate Bipolar Transistor
PWM	-	Pulse Width Modulation
RPM	-	Rotations Per Minute
N.m	-	Newton.Metre
Tlstarting	-	Starting Load Torque
Wref	-	Reference Speed

CHAPTER 1

Introduction

1.1 Motivation

Electrical Energy already constitutes more than 30 % of all energy usage on Earth. And this is set to rise in the coming years. Its massive popularity has been caused by its efficiency of use, ease of transportation, ease of generation, and environment-friendliness. Part of the total electrical energy production is sued to produce heat, light, in electrolysis, arc-furnaces, domestic heating etc. Another large part of the electrical energy production is used to be converted into mechanical energy via different kinds of electric motors- DC Motors, Synchronous Motors and Induction Motors.

Induction Motors are often termed the "Workhorse of the Industry". This is because it is one of the most widely used motors in the world. It is used in transportation and industries, and also in household appliances, and laboratories. The major reasons behind the popularity of the Induction Motors are:

i. Induction Motors are cheap compared to DC and Synchronous Motors. In this age of competition, this is a prime requirement for any machine. Due to its economy of procurement, installation and use, the Induction Motor is usually the first choice for an operation.
ii. Squirrel-Cage Induction Motors are very rugged in construction. There robustness enables them to be used in all kinds of environments and for long durations of time.
iii. Induction Motors have high efficiency of energy conversion. Also they are very reliable.
iv. Owing to their simplicity of construction, Induction Motors have very low maintenance costs.
v. Induction Motors have very high starting torque. This property is useful in applications where the load is applied before starting the motor.

Another major advantage of the Induction Motor over other motors is the ease with which its speed can be controlled. Different applications require different optimum speeds for the motor to run at. Speed control is a necessity in Induction Motors because of the following factors:

i. It ensures smooth operation.
ii. It provides torque control and acceleration control.

iii. Different processes require the motor to run at different speeds.
iv. It compensates for fluctuating process parameters.
v. During installation, slow running of the motors is required.

All these factors present a strong case for the implementation of speed control or variable speed drives in Induction Motors.

1.2 Induction Motors: A Brief History

The seeds for the development of the Induction Motor were sown with Faradey's discovery of the Laws of Electromagnetic Induction in 1831 and with Maxwell's formulation of the laws of electricity in 1860.

The Induction Machine was independently developed by Galileo Ferrari in 1885 and by Nikola Tesla in 1886. Ferrari's model had a rotor made up of a copper cylinder. Tesla used a ferromagnetic cylinder with a short-circuited winding. However, the underlying principles and basic design philosophies of both models were similar. George Westinghouse licensed Tesla's patents and developed a practical Induction Motor in 1892. To this date, apart from the vast improvements in performance and refinements in design, the basics of the Induction Machine remain the same.

In 1896, General Electric and Westinghouse signed a cross-licensing agreement for the Squirrel-Cage design of the Induction Motor, and by 1900, it was all set to become the industrial staple. By 1910, locomotives in Europe were fitted with Induction Motors and were able to attains speeds in excess of 200 km/hr.

However, faster strides in the development of DC Motors made it overtake Induction Motors when it came to usage in the industry or in transportation. The latter again made a comeback in 1985 with the development of Power Electronics-based drives, especially IGBT-based PWM Inverters for efficient frequency-changing. The following are some of the recent developments in Induction Motor drives:

i. Better analytical models for design and research purposes.

ii. Better magnetic and insulation materials and cooling systems.
iii. Availability of design optimization tools.
iv. IGBT-based PWM Inverters for efficient frequency changing with low losses and high power density.
v. New and better methods for manufacturing and testing.
vi. High speed and high power applications.

With a widespread presence in all kinds of industries, households and in transportation, the Induction Motor is now called the ‘Racehorse of the Industry’.

1.3 V/f Control of Induction Motor Drive: An Introduction

There are various methods for the speed control of an Induction Motor. They are:

i. Pole Changing
ii. Variable Supply Frequency Control
iii. Variable Supply Voltage Control
iv. Variable Rotor Resistance Control
v. V/f Control
vi. Slip Recovery
vii. Vector Control

Of the above mentioned methods, V/f Control is the most popular and has found widespread use in industrial and domestic applications because of its ease-of-implementation. However, it has inferior dynamic performance compared to vector control. Thus in areas where precision is required, V/f Control are not used. The various advantages of V/f Control are as follows:

i. It provides good range of speed.
ii. It gives good running and transient performance.
iii. It has low starting current requirement.
iv. It has a wider stable operating region.
v. Voltage and frequencies reach rated values at base speed.
vi. The acceleration can be controlled by controlling the rate of change of supply frequency.

vii. It is cheap and easy to implement.

1.4 Objective of the Project

The main objective of the project is to develop a model or models to implement V/f control of an induction motor. In order to do that, one must be familiar with the PWM Inverter which drives the induction motor. Hence, PWM signal generation, and Inverter topologies are also studied and simulated.

1.5 Scope of the Thesis

i. Development Simulink models for a PWM Inverter.

ii. Using the developed PWM Inverter Simulink model to run an Induction Motor, and obtain its uncontrolled speed, torque, and current characteristics.

iii. Development of a V/f Control scheme for controlling the Induction motor- both Open Loop and Closed Loop using MATLAB.

1.6 Organization of the Thesis

Chapter 2 deals with the basics of the Induction Motor drive and presents a case for the need for an efficient speed control scheme.

Chapter 3 deals with Pulse Width Modulation-based Inverters. Single-phase and Three-phase PWM Inverters are presented and simulated for different kinds of loads

Chapter 4 deals with V/f Control of PWM-Inverter fed Induction Motors. Uncontrolled characteristics are obtained and contrasted with controlled characteristics. Successful speed control is achieved.

Chapter 5 summarizes all the results obtained and lists the conclusions based on those results.

CHAPTER **2**

Induction Motor Drives

2.1 Introduction

Induction Motors account for more than 85% of all motors used in industry and domestic applications. In the past they have been used as constant-speed motors as traditional speed control methods have been less efficient than speed control methods for DC motors. However, DC Motors require commutators and brushes which are hazardous and require maintenance. Thus Induction Motors are preferred.

2.2 Construction

The Induction Motor has a stator and a rotor. The stator is wound for three phases and a fixed number of poles. It has stampings with evenly spaced slots to carry the three-phase windings. The number of poles is inversely proportional to the speed of the rotor. When the stator is energized, a moving magnetic field is produced and currents are formed in the rotor winding via electromagnetic induction. Based on rotor construction, Induction Motors are divided into two categories.

In *Wound-Rotor Induction Motors,* the ends of the rotor are connected to rings on which the three brushes make sliding contact. As the rotor rotates, the brushes slip over the rings and provide a connection with the external circuit.

In *Squirrel-Cage Induction Motors,* a "cage" of copper or aluminium bars encase the stator. These bars are then shorted by brazing a ring at the end connecting all the bars. This model is the more rugged and robust variant of the Induction Motor.

2.3 Working

When the stator winding is energized by a three-phase supply, a rotating magnetic field is set-up which rotates around the stator at synchronous speed *Ns.* This flux cuts the stationary rotor and induces an electromotive force in the rotor winding. As the rotor windings are short-circuited a current flows in them. Again as these conductors are placed in the stator's magnetic field, this exerts a mechanical force on them by Lenz's law. Lenz's law tells us that the direction of rotor currents will be such that they will try to oppose the cause producing them. Thus a torque is produced which tries to reduce the relative speed between the rotor and the magnetic field. Hence the rotor will rotate in the same direction as the flux. Thus the relative speed between the rotor and the speed of the magnetic field is what drives the rotor. Hence the rotor speed *Nr* always remains less than the synchronous speed *Ns*. Thus Induction Motors are also called Asynchronous Motors.

2.4 Torque-Speed Analysis

The equivalent circuit of an Induction Motor can be depicted as shown below:

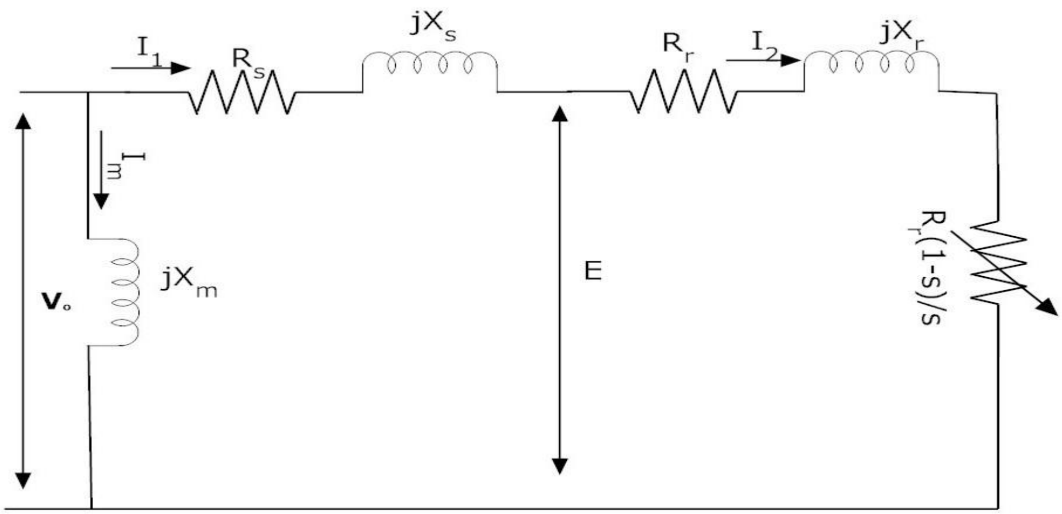

Figure 1: Equivalent Circuit of an Induction Motor

Where Xm= Magnetizing Reactance

Xs= Stator Reactance

Xr= Rotor Reactance

Rs= Stator Resistance

Rr= Rotor Resistance

s= slip

In an Induction Motor the slip is given as

$$s = \frac{Ns - Nr}{Ns} \qquad (1)$$

Where Ns= Synchronous speed

Nr= Rotor speed

The following expressions can be derived from the above circuit,

Rotor Current

$$I2 = \frac{Vo}{\left(Rs + \frac{Rr}{s}\right) + j\,(Xs + Xr)} \qquad (2)$$

Torque

$$T = \pm \frac{\left(\frac{3Vo^{2}Rr}{s}\right)}{ws\left[\left(Rs + \frac{Rr}{s}\right)^{2} + (Xs + Xr)^{2}\right]} \qquad (3)$$

The following are the torque and speed characteristics for an Induction Motor

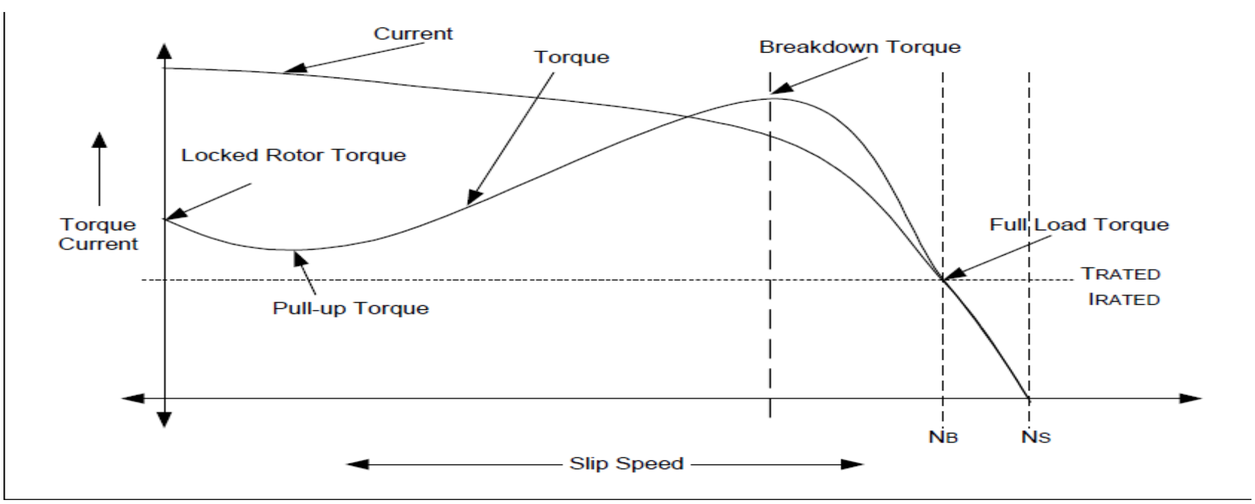

Figure 2: Torque and Speed Curves for an Induction Motor

Figure 2 shows a the ideal torque-speed characteristics of an Induction motor. The X-axis shows speed and slip while the Y-axis shows Torque and Current. When the motor is started, it draws very large current to the tune of seven times the rated current, which is a result of the stator and rotor flux. Also the starting torque is around 1.5 times the rated value for the motor.

As the speed increases, the current reduces slightly and then drops significantly when the speed reaches close to 80% of the rated speed. At the base speed, the rated current flows in the motor and rated torque is delivered.

At base speed, if the load is increased beyond the value for the rated torque, the speed drops and the slip increases. At a speed of 80% of the Synchronous speed, the load increases up to 2.5 times the rated torque, this is called the breakdown torque. Increasing the load further causes the torque to fall rapidly and the motor stalls.

CHAPTER **3**

PWM Inverter

3.1. <u>Introduction</u>

There are various kinds of modulation that are used for the communication of information. When the amplitude of a high frequency signal is varied according to a low frequency signal it is called AM, or Amplitude Modulation. When the frequency of a signal is modified according to the modulating signal, it is called FM, or Frequency Modulation. These are the two schemes most commonly used in radio transmissions. Since communication via pulses has been introduced, the amplitude, frequency and width of pulses started being modulated by the message signal. The latter gave rise to PWM, or Pulse-Width Modulation. The various kinds of PWM are:

i. **Linear PWM:** This is the simplest scheme where the average ON time of the pulses is varied proportionally with the modulating signal.
ii. **Sawtooth PWM:** In this scheme, the comparison of the signal is made with a sawtooth wave. The output signal goes high when the signal is higher than the sawtooth and goes low when it is lower. This is done with the help of a comparator. This helps in the generation of a fixed frequency PWM wave.
iii. **Regular Sampled PWM:** Here, the width of the pulse is made proportional to the value of the modulating signal at the beginning of the carrier period.

3.2. Single-Phase PWM Inverter

An Inverter is a circuit which converts a DC power input into an AC power output at a desired output voltage and frequency. This conversion is achieved by controlled turn-on and turn-off devices like IGBT's. Ideally, the output voltage of an Inverter should be strictly sinusoidal. However the outputs are usually rich in harmonics and are almost always non-sinusoidal. Square-wave and quasi-square-wave voltages are acceptable.

The DC power input to the inverter may be a battery, a fuel cell, solar cell or any other DC source. Most industrial applications use a rectifier which takes AC supply from the mains and converts it into DC to feed it to the inverter. Modelling a single-phase Inverter consists of the following steps:

i. Designing a Power Circuit.

ii. Designing a Control Circuit.

The following Single-phase Inverter circuit was modelled in MATLAB-Simulink

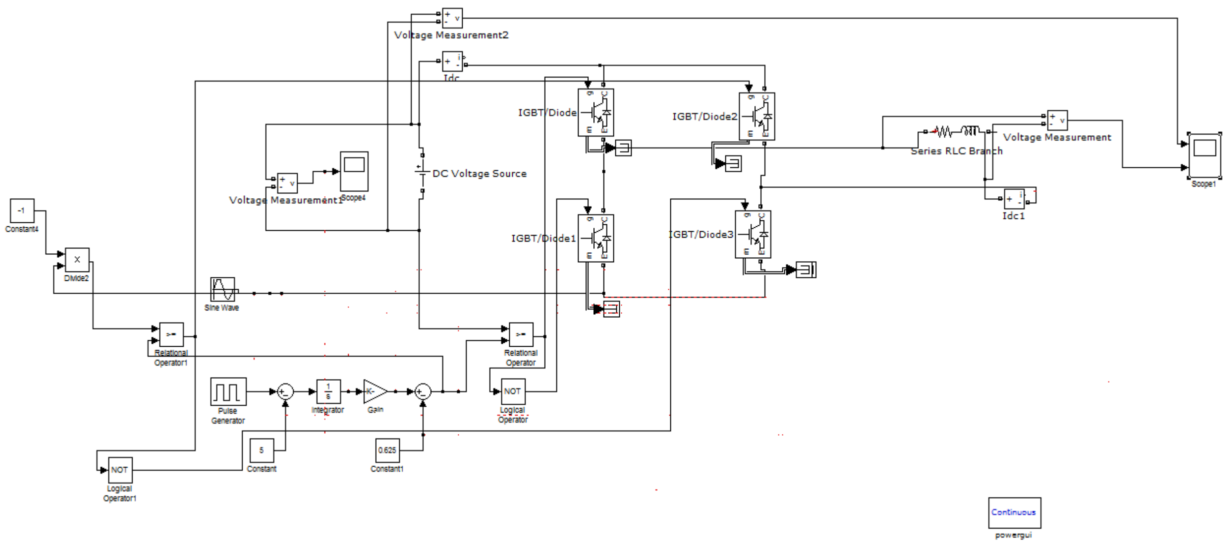

Figure 3: Simulink Model for 1-Phase Inverter with Resistive Load

i. Modelling the Power Circuit:

The Power Circuit of the Single-Phase Inverter consists of 4 bidirectional IGBT's arranged in bridge-form. The input to the circuit is a 400 V DC supply from a battery. The IGBT/Diodes are triggered in two distinct cycles.

In the first cycle, from 0 to 180 degrees, IGBT/Diode and IGBT/Diode3 are triggered by applying signal to their gates. Thus they conduct during this period and output is obtained across the load.

In the next cycle, from 180 to 360 degrees, IGBT/Diode1 and IGBT/Diode2 are trigeered and they conduct during this period. Hence the output of 400 V is obtained across the load in the opposite direction. Thus a DC supply voltage is converted to AC voltage across the load and Inverter action is obtained.

ii. Modelling the Control Circuit:

The Control Circuit consists of a PWM Generator. The PWM signals are obtained by comparing a sine wave with a pulse train and modulating the pulse width accordingly. As can be seen the pulse train is integrated and then compared to the sinusoidal signal. The PWM signal is generated with the help of >= operator. These PWM signals are applied to the gates of the IGBT's so as to trigger them. While one pair of IGBT's are fed signals directly from the relational operator, the other pair is fed the signal after passing through the NOT gate. Thus the two pairs are switched ON in alternating cycles of operation.

The following output was obtained when the circuit was simulated in the MATLAB-Simulink environment-

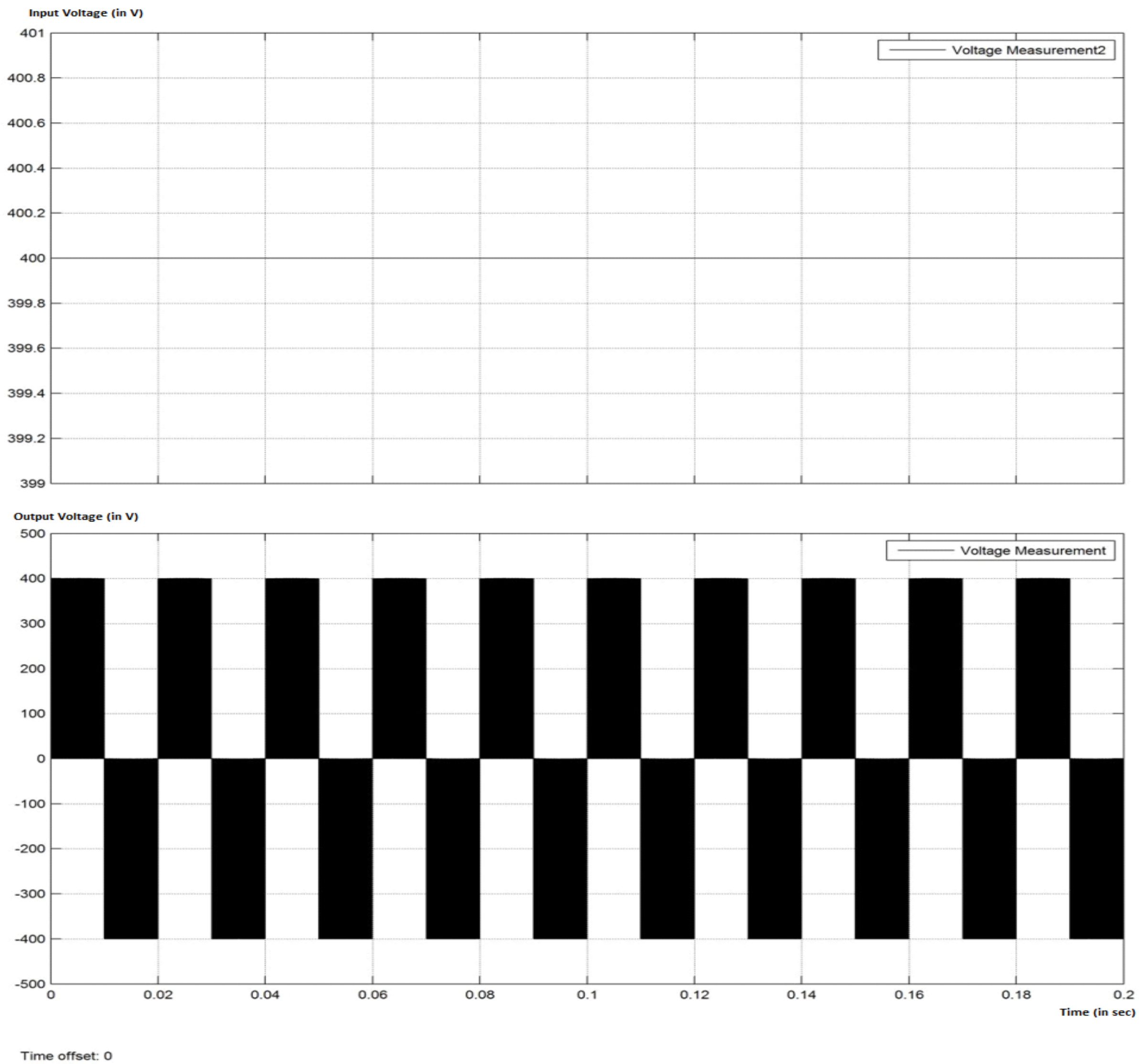

Figure 4: Input and Output Voltage for Single-Phase PWM Inverter

As can be seen, for an input DC voltage of 400 V, the circuit produced an output AC voltage which had maximum voltage amplitude of 400 V. Thus Inverter action was obtained.

3.3. Three-Phase PWM Inverter

The model used to simulate the Single-Phase Inverter was extended for the modeling of a 3-Phase PWM Inverter.

In this case, the power circuit was made up of 3 arms containing two IGBT/Diodes each. The circuit was operated in 120 degrees mode, i.e. IGBT's 1, 2, 3, 4, 5 and 6 were fired in that order 60 degrees apart. This produced a 3-phase output with a phase difference of 120 degrees between the three phases.

The control circuit used was also an extension of the one used previously in the Single-Phase Inverter model. The only difference was that in this case 2 sine waves were taken and compared with a triangular wave. The sine waves were given an amplitude of 0.5625 and a frequency of 50 Hz.

The following circuit was modeled using MATLAB-Simulink-

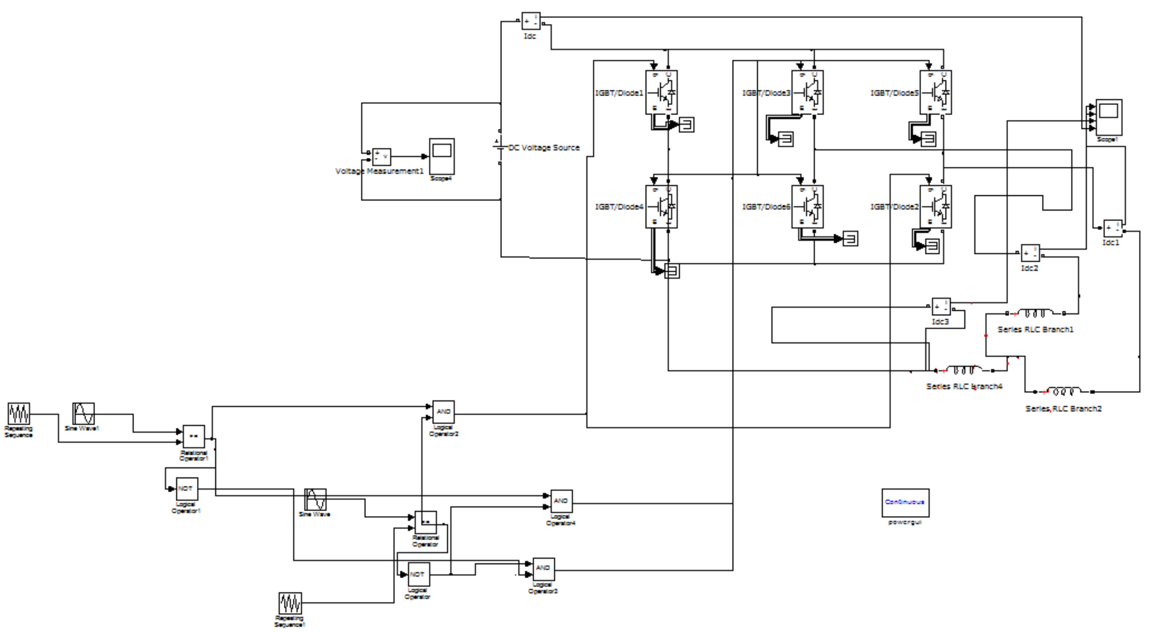

Figure 5: Simulink Model for 3-Phase PWM Inverter

The above circuit was simulated for 0.1 seconds and the current outputs of the 3 phases along with the input current were observed.

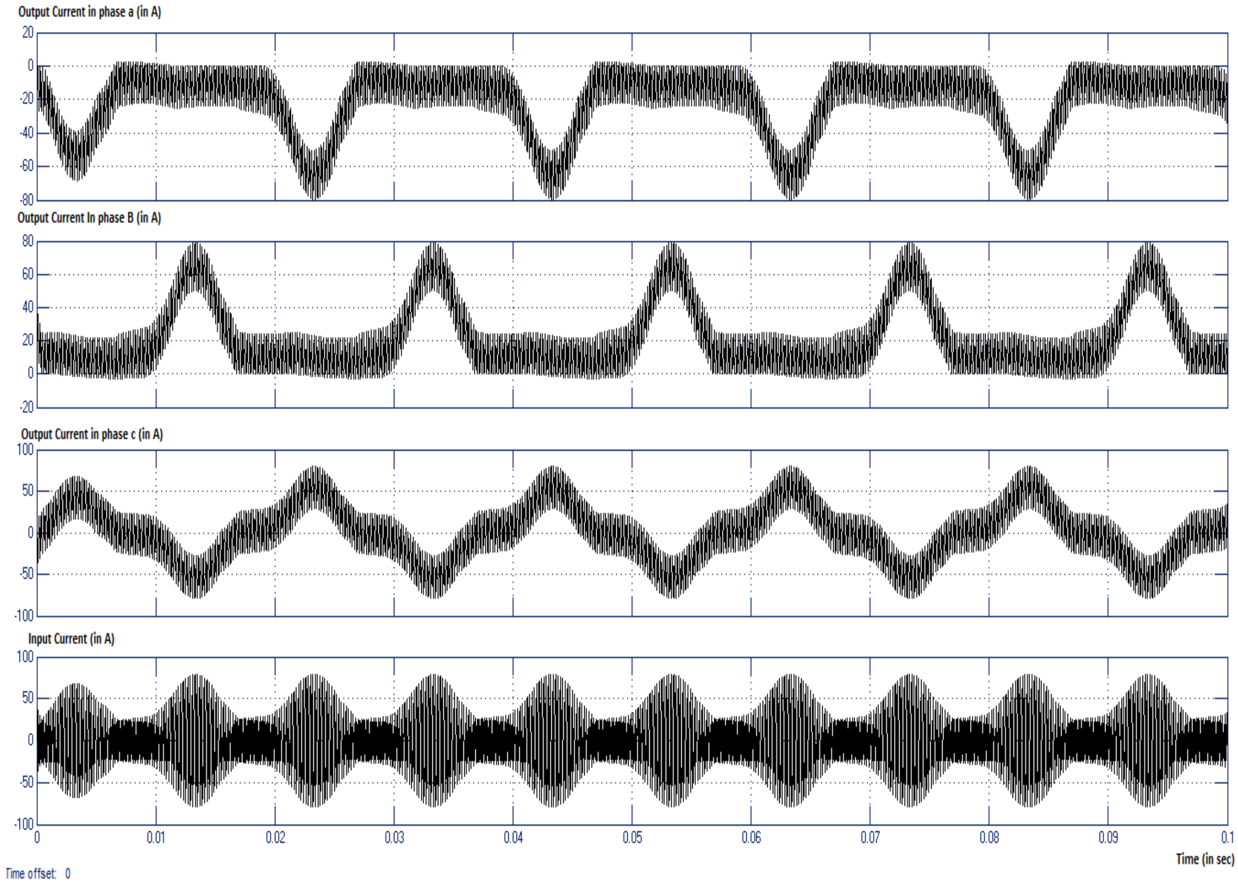

Figure 6: Output and Input Current Waveforms for 3-phase PWM Inverter

It was observed that a large amount of harmonics were present in the current waveforms. However the output current in phase c was found to be a proper AC waveform. This output was obtained for an input voltage of 400 V DC. Hence Inverter action was obtained.

As perfect output waveforms are a requirement for the smooth running of the Induction Motor, a PWM Inverter was modeled with the help of Simulink Library Blocks-

i. Universal Bridge: This block implements a universal 3-phase power convertor that consists of upto 6 switches connected in a bridge configuration. The following parameters were passed-
   - No. of bridge arms= 3
   - Snubber resistance= 10000 Ω
   - Snubber capacitance- inf
   - Power Electronic Device- IGBT/Diode

- Ron= (1e-4) Ω
- Forward Voltages= [1 1]
- [Tf(s), Tf(s)]= [1e-6, 2e-6]

ii. PWM Generator- This block generates pulses for PWM for firing the bridges of forced-commutation devices. The pulses are generated by comparing a triangular carrier waveform to a reference signal. The following parameters were passed-
  - Generator mode- 3-arm bridge (6 pulses)
  - Carrier frequency= 2160 Hz
  - Yes for Internal generation of modulating signal
  - Modulation Index= 0.7
  - Freq of output voltage= 60 V
  - Phase of output voltage= 0 degrees

The following is the schematic developed using Simulink-

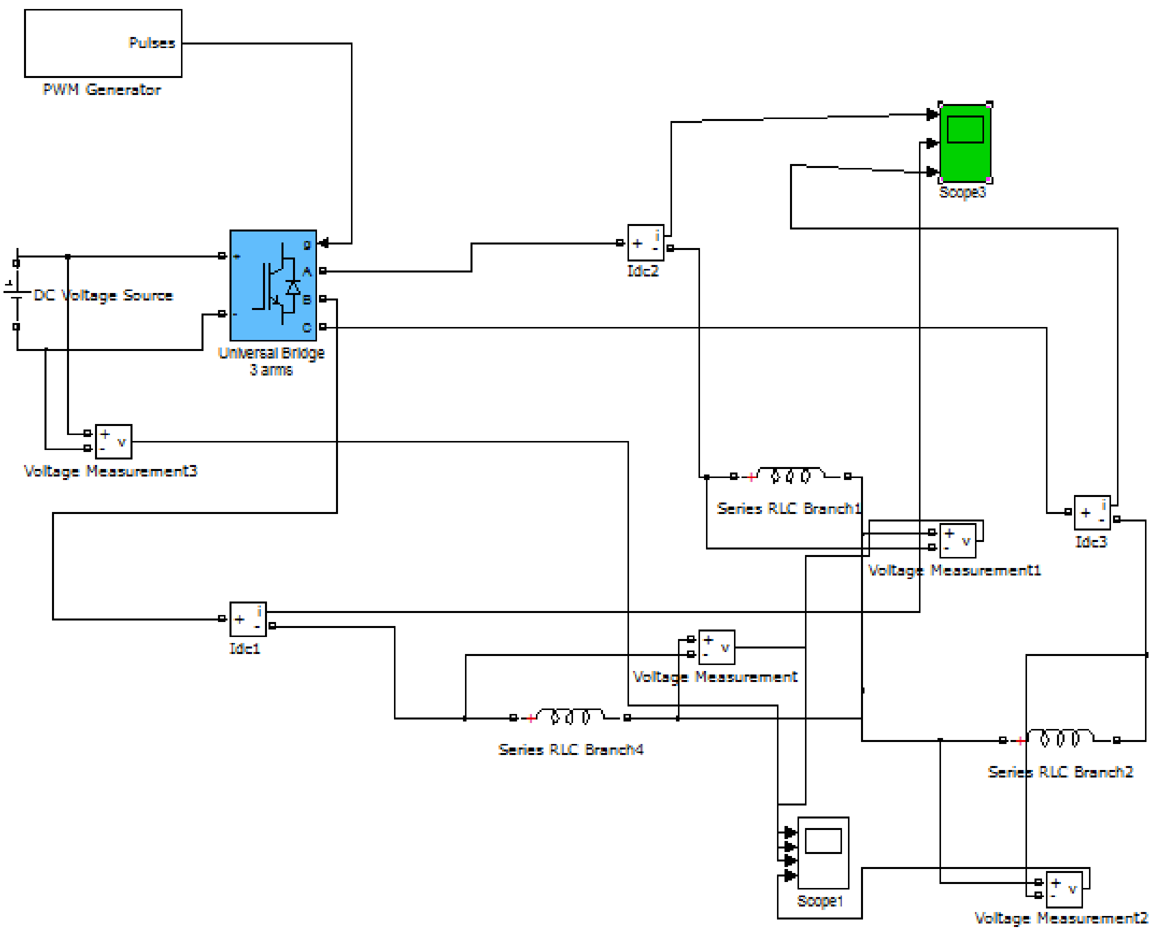

Figure 7: 3-phase PWM Inverter using Simulink Blocks

As can be observed, using the blocks from the Simulink library greatly reduces the complexity of the model. The following input and output voltage waveforms were observed-

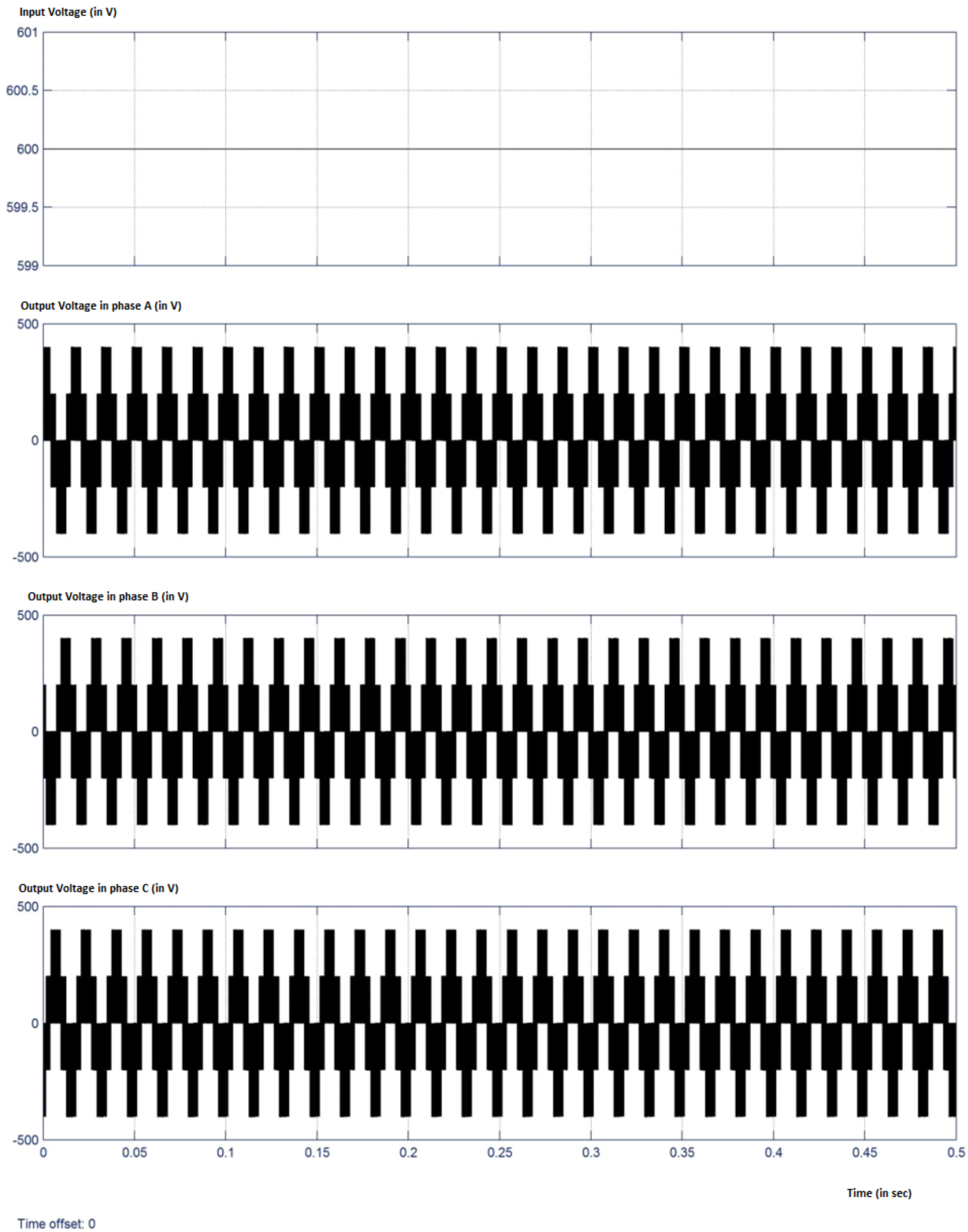

Figure 8: Input and Output Waveforms for 3-phase PWM Inverter with Inductive Load

As can be seen, for an input DC voltage of 600 V, the circuit produces 3-phase AC voltage output. The load is Y-connected and purely inductive in nature. The output voltages of the three phases are 120 degrees apart from one another. Thus Inverter action was obtained.

CHAPTER **4**

V/f Control of Induction Motor

4.1 Introduction

Synchronous speed can be controlled by varying the supply frequency. Voltage induced in the stator is $E_1 \propto \Phi f$ where Φ is the air-gap flux and f is the supply frequency. As we can neglect the stator voltage drop we obtain terminal voltage $V_1 \propto \Phi f$. Thus reducing the frequency without changing the supply voltage will lead to an increase in the air-gap flux which is undesirable. Hence whenever frequency is varied in order to control speed, the terminal voltage is also varied so as to maintain the V/f ratio constant. Thus by maintaining a constant V/f ratio, the maximum torque of the motor becomes constant for changing speed.

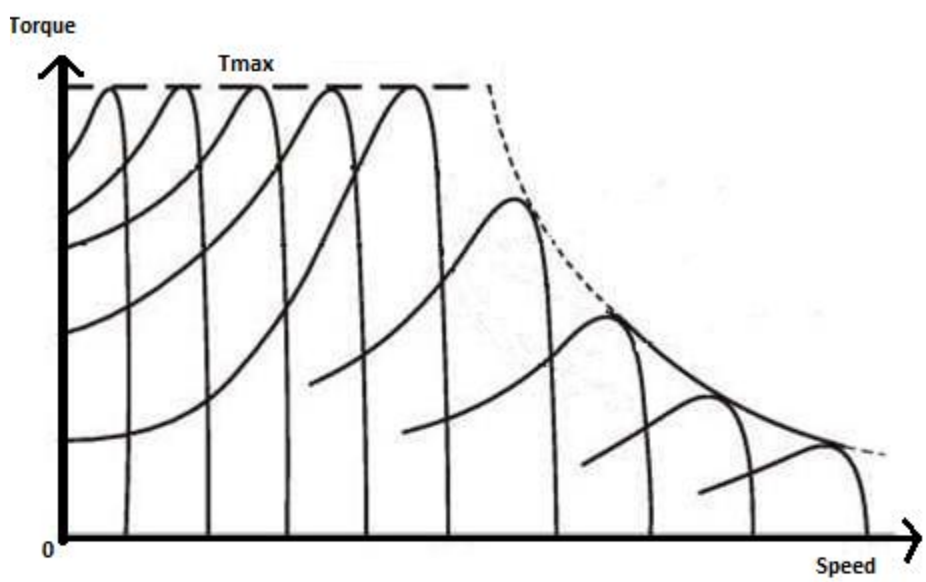

Figure 9: Torque-Speed characteristics for V/f Controlled Induction Motor

As can be seen, when V/f Control is implemented, for various frequencies inside the operating region, the maximum torque remains the same as the speed varies. Thus maintaining the V/f ratio constant helps us to maintain a constant maximum torque while controlling the speed as per our requirement.

4.2 Uncontrolled PWM Inverter-fed Induction Motor

First we shall study the characteristics of an uncontrolled Induction Motor that is fed via a PWM Inverter. The 3-phase PWM Inverter modeled previously in the last chapter was used. The Power Circuit was modeled using a Universal Bridge and the Control Circuit, using a PWM Generator. The output of the PWM Generator block was supplied to the 'gate' of the Universal Bridge. The 3-phase output of the Inverter was then fed to the Induction Motor, The Induction Motor was modeled using the Simulink Block 'Asynchronous Machine'. A starting load torque of 20 N.m was also applied to it.

The Simulink model is as follows-

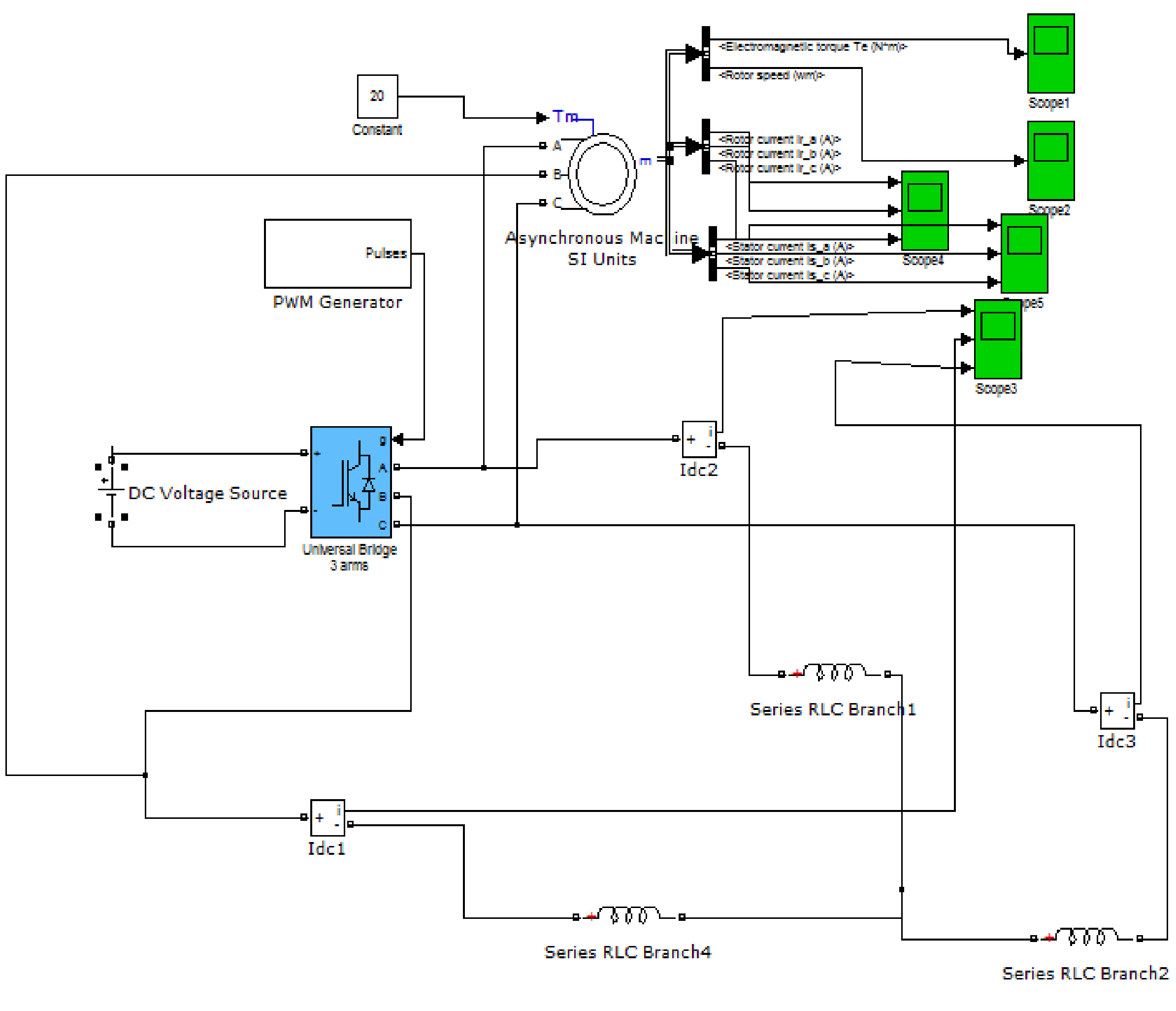

Figure 10: 3-Phase Induction Motor fed by PWM Inverter

The following parameters were passed for the PWM Generator block-

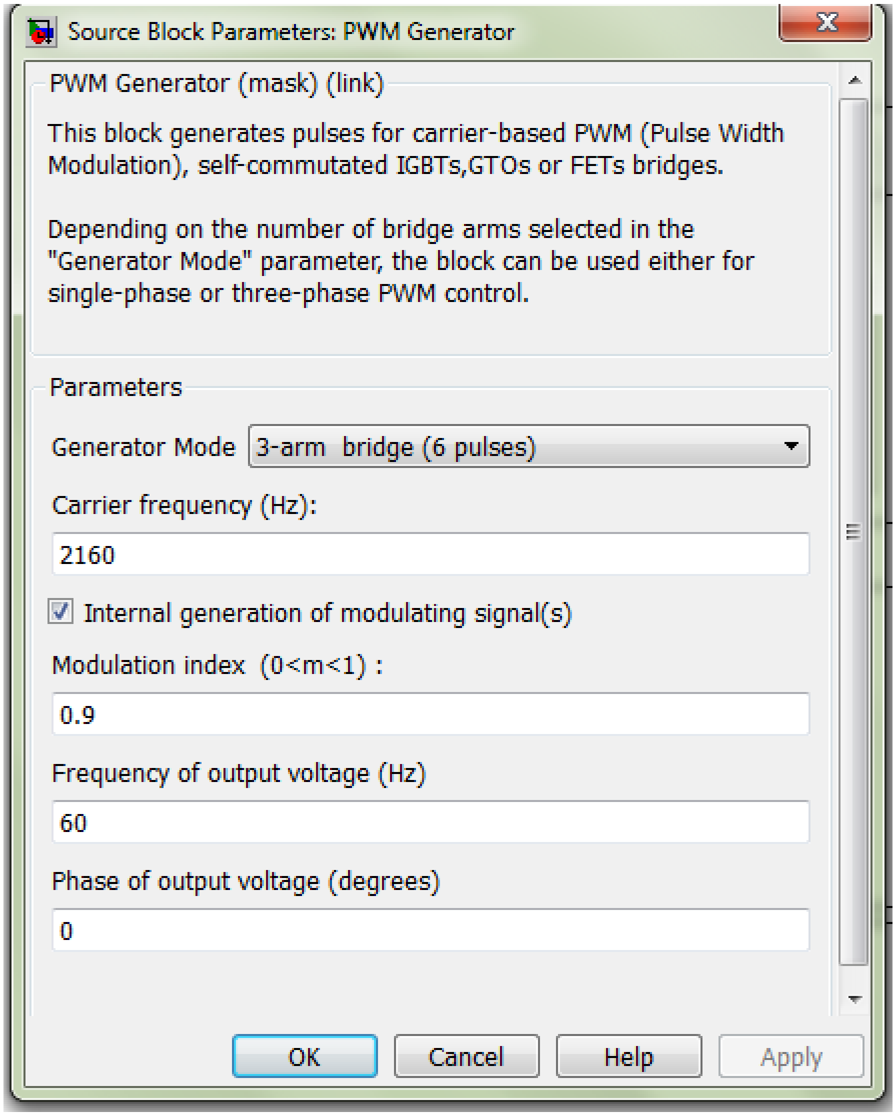

Figure 11: Parameters passed for PWM Generator block

The following parameters were passed for the Universal Bridge block-

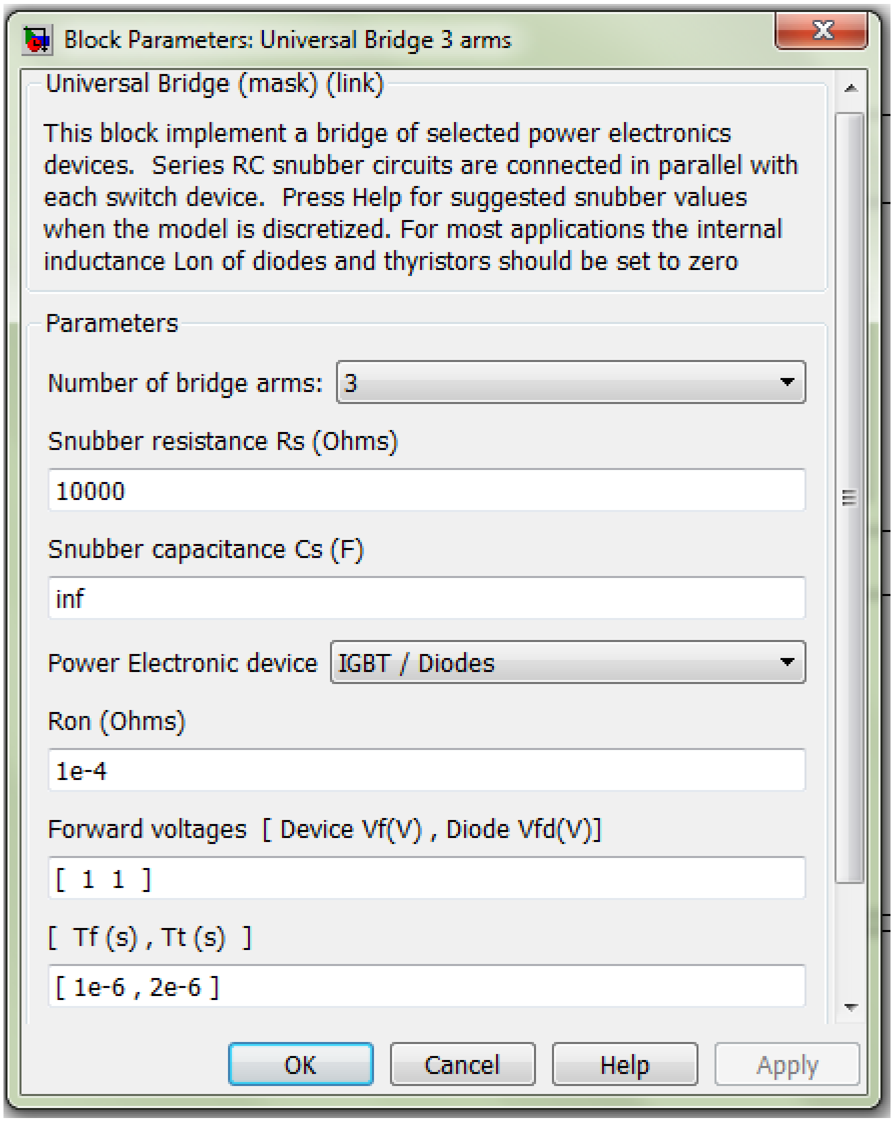

Figure 12: Parameters for Universal Bridge block

The following parameters were passed for the Asynchronous Machine block-

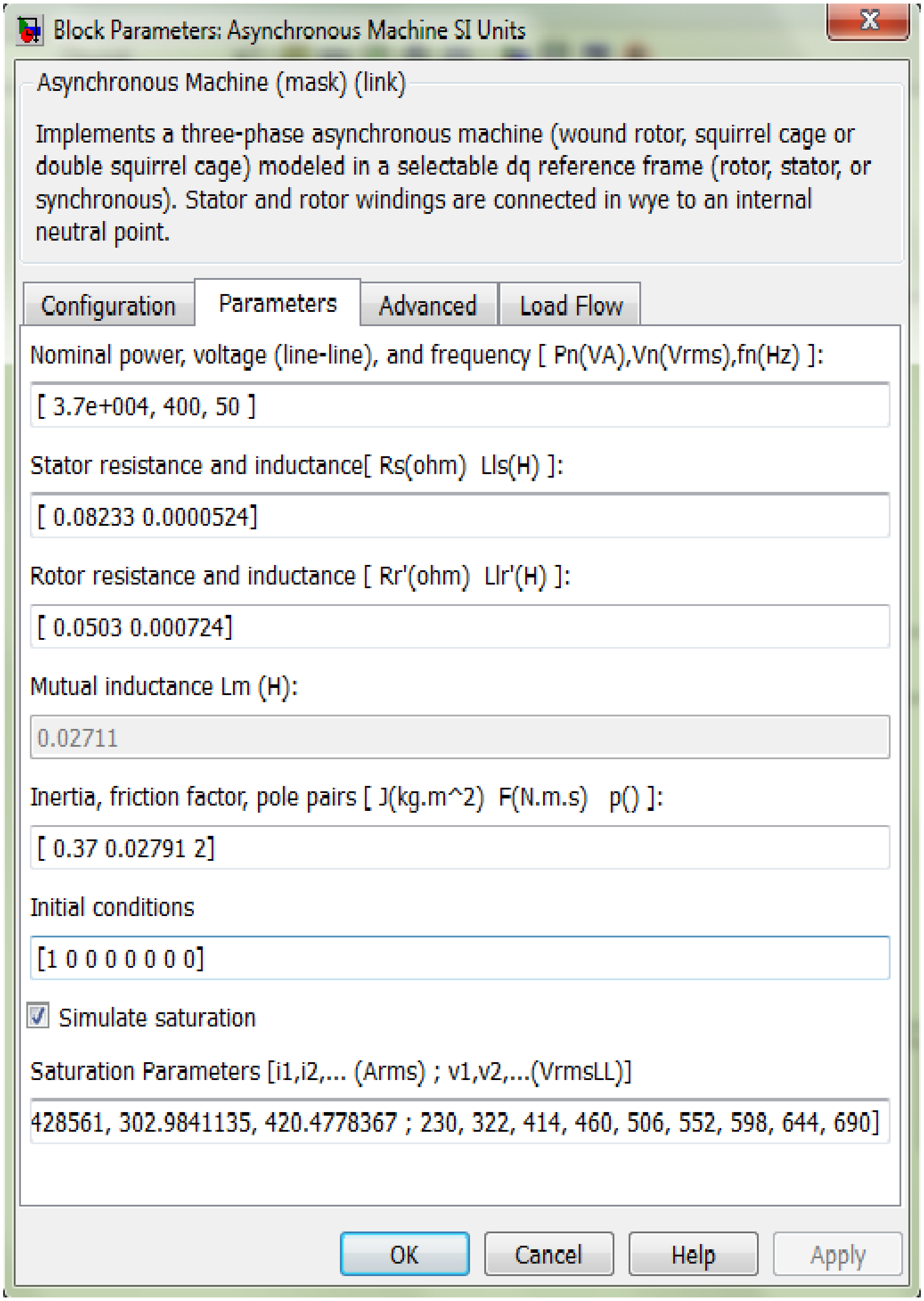

Figure 13: Parameters for Asynchronous Machine block

The above model was simulated in a MATLAB-Simulink environment. The output waveforms for torque, rotor speed, rotor current and stator current were obtained. They are as follows-

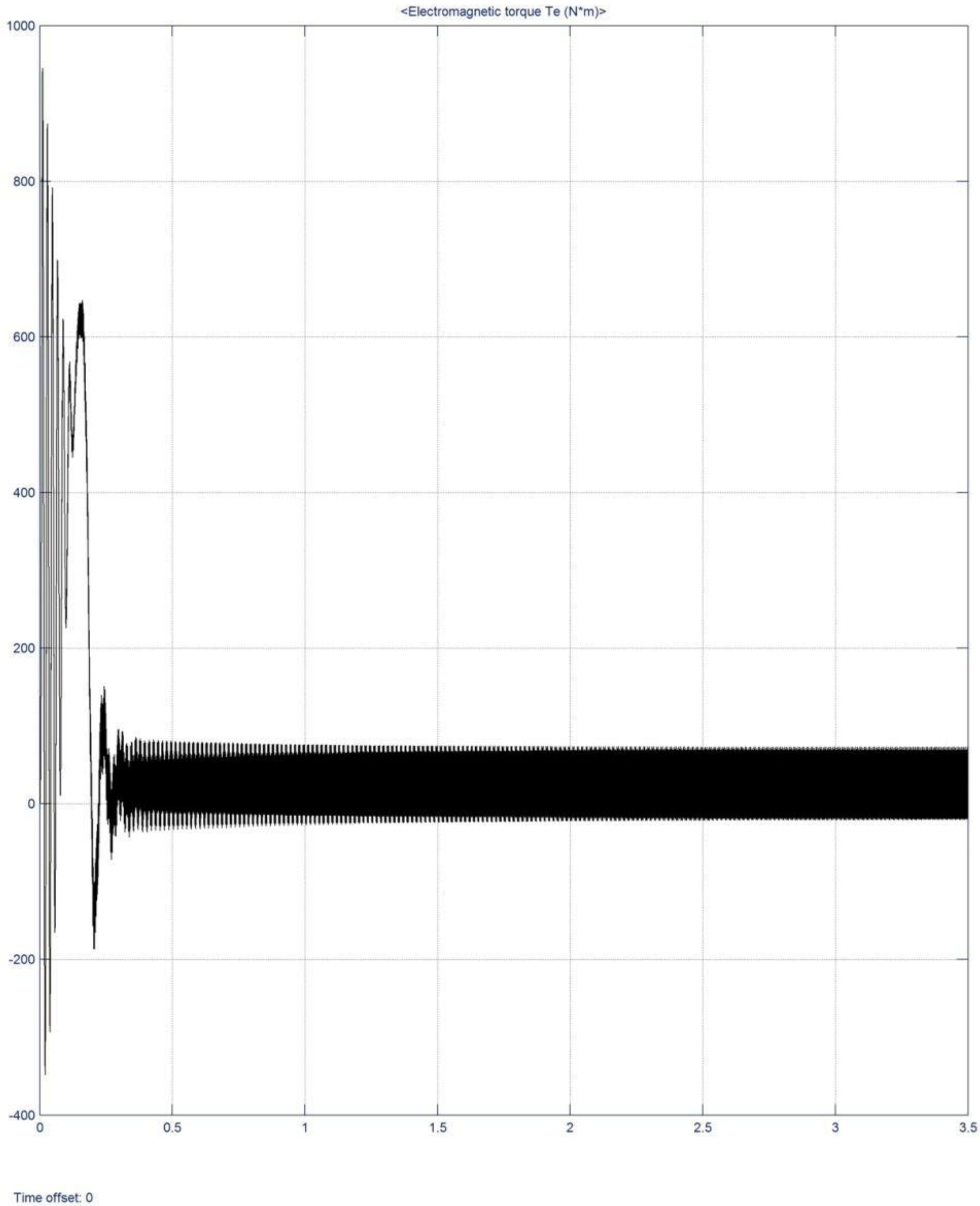

Figure 14: Torque characteristics for Uncontrolled Induction Motor

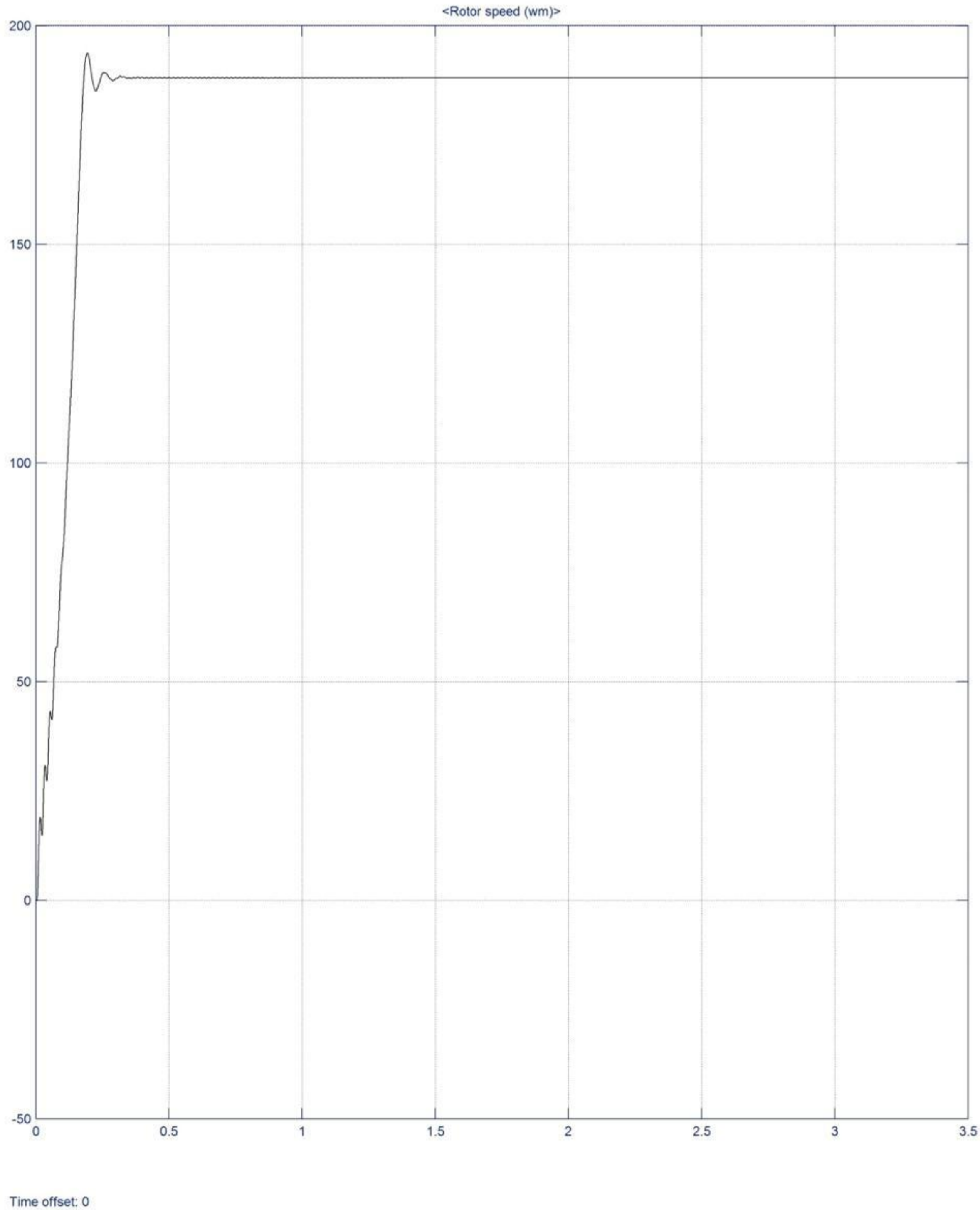

Figure 15: Speed Characteristics for Uncontrolled Induction Motor

As can be seen, the Induction Motor exhibits very high transients during starting. At steady-state the torque first rises to maximum value called the ‘Breakdown Torque’ after which it settles down at a base value give as 20 N.m. It is also observed that the rotor speed increases to its rated value and stays constant at that value.

The following are rotor and stator currents in the Induction Motor:

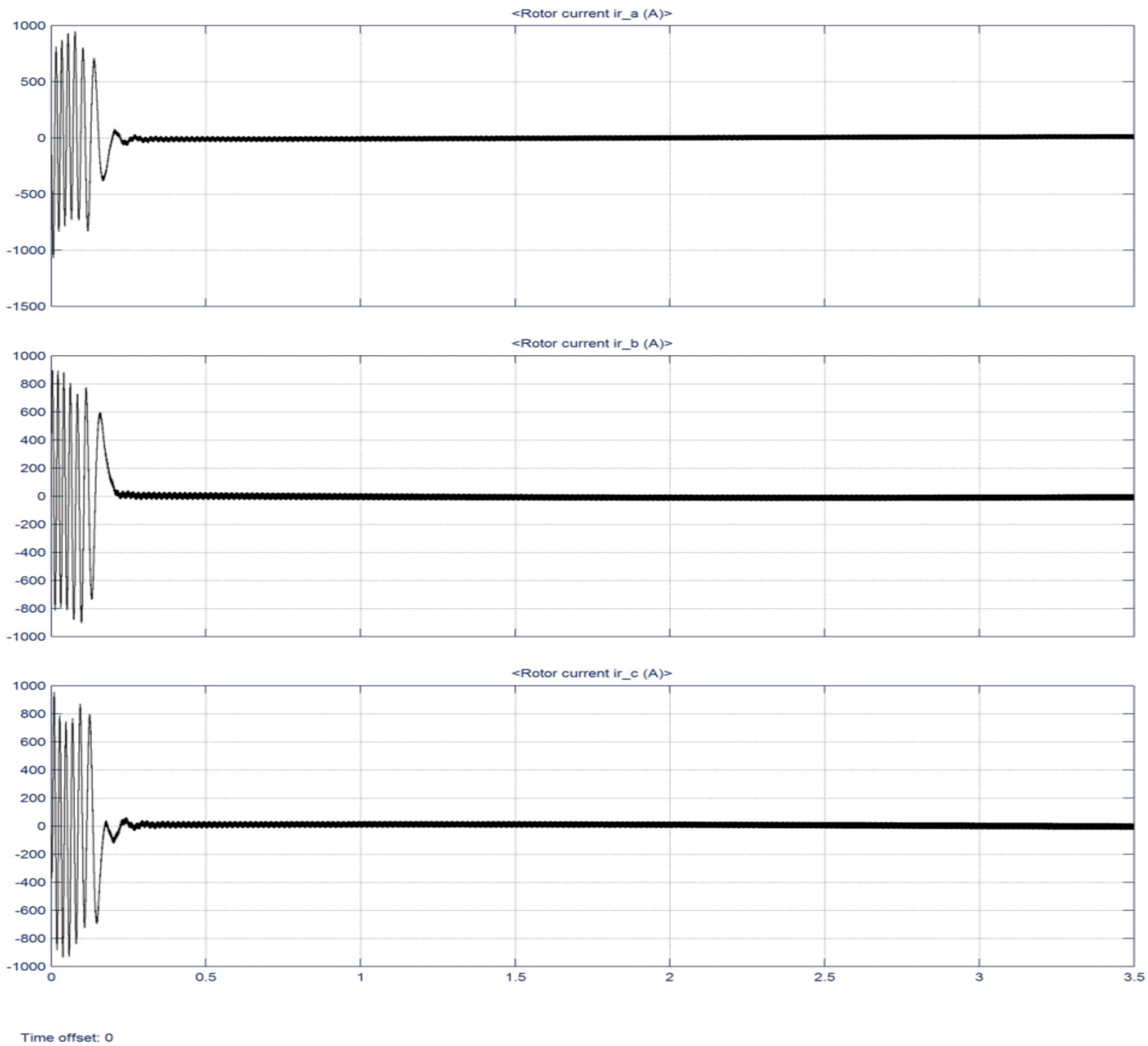

Figure 16: Rotor Current Characteristics for Uncontrolled Induction Motor

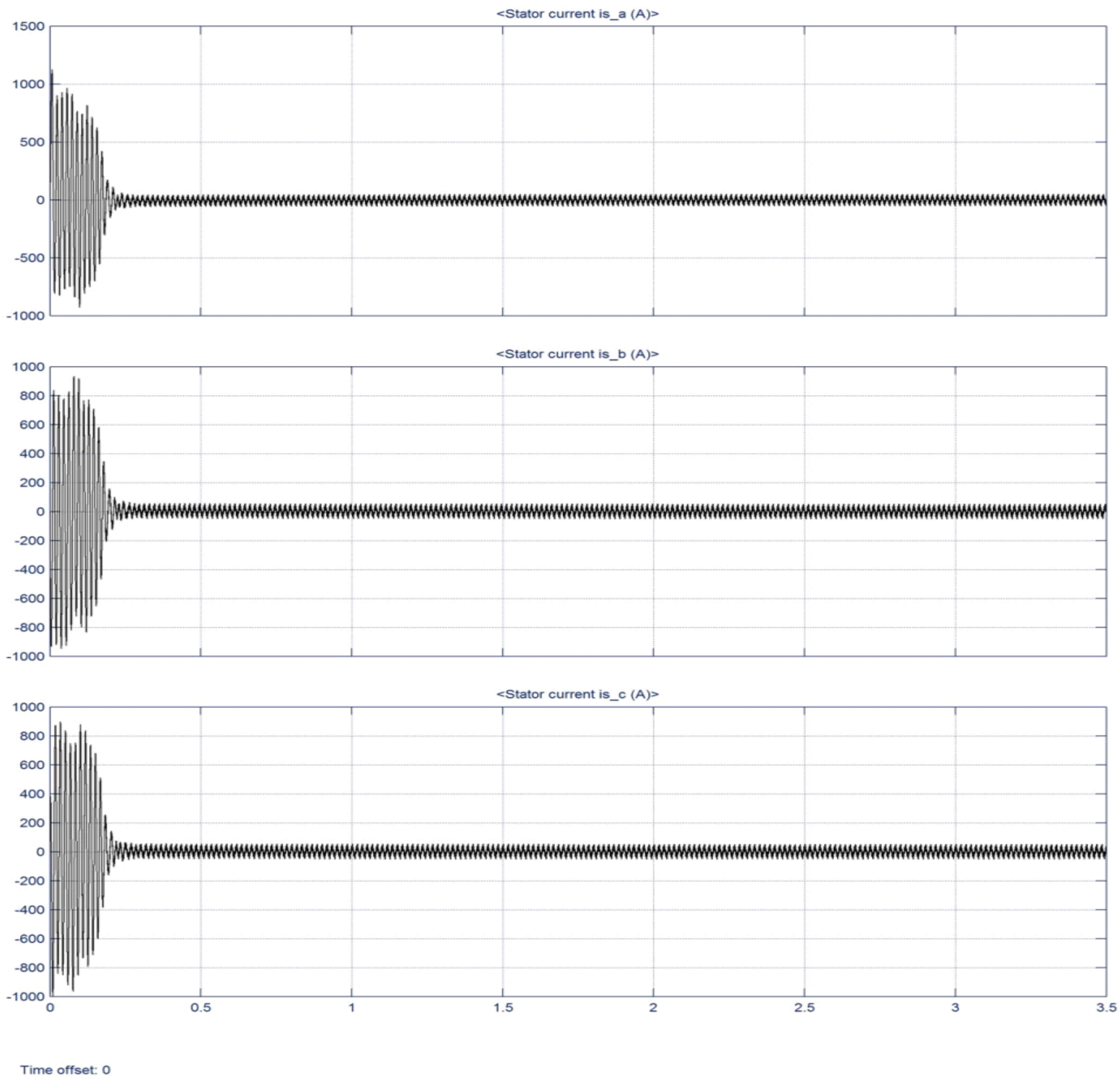

Figure 17: Stator Current Characteristics for Uncontrolled Induction Motor

As can be observed both the stator and rotor currents exhibited high transients during the starting of the motor. They then settled down to low amplitude sinusoidal oscillations.

4.3 Open-loop V/f Control using MATLAB

In this method, the stator voltage was varied, and the supply frequency was simultaneously varied such that the V/f ratio remained constant. This kept the flux constant and hence the maximum torque while varying the speed.

A MATLAB code was developed which asked the user to input different frequencies and then varied the voltage to keep the V/f ratio constant. The different synchronous speeds corresponding to the different frequencies were calculated and the torque characteristics were plotted as the rotor speed was incremented from zero to the synchronous speed in each case. The resulting Torque vs Speed graph was plotted.

The following machine details were used to execute the code-

- RMS Value of line-to-line supply voltage= 415 V
- No. of poles= 4
- Stator Resistance= 0.075Ω
- Rotor Resistance= 0.1Ω
- Frequency= 50 Hz
- Stator Reactance @ 50 Hz= 0.45Ω
- Rotor Reactance @ 50 Hz= 0.45Ω

The MATLAB code was executed and the following plot was obtained.

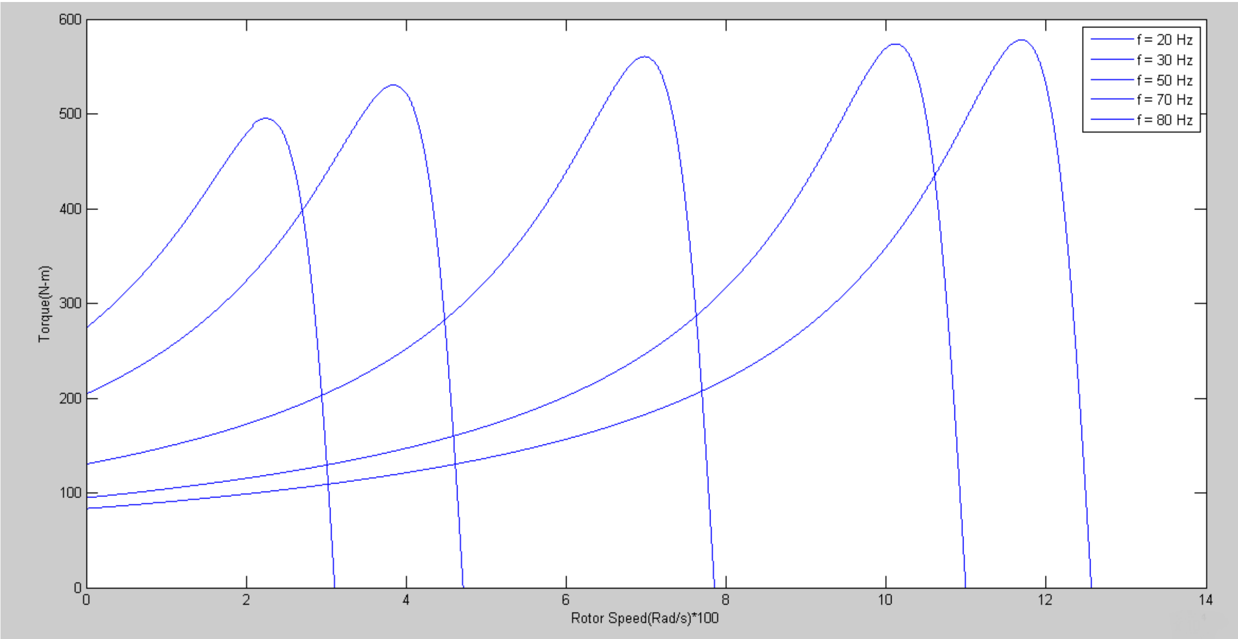

Figure 18: Torque vs Speed Curves for Open-loop V/f Controlled Induction Motor for various frequencies

As can be seen the Maximum Torque of the Induction Motor remains constant, across the speed range, while the frequency is varied

The AC supply from the mains is supplied to a rectifier which converts into DC and this is fed to the PWM Inverter. The PWM Inverter varies the frequency of the supply and the voltage is varied accordingly to keep the ratio constant. The electromagnetic torque is directly proportional to the flux produced by the stator which is in turn directly proportional to the ratio of the terminal voltage and the supply frequency. Hence by varying the magnitudes of V and f while keeping the V/f ratio constant, the flux and hence the torque can be kept constant throughout the speed range.

4.4 Closed-Loop V/f Control of Induction Motor using MATLAB

In closed-loop V/f Control the speed of the rotor is measured using a sensor and it is compared to the reference speed. The difference is taken as the error and the error is fed to a Proportional controller. The P controller sets the inverter frequency. The frequency is taken as input for the

Voltage Source Inverter which modifies the terminal voltage accordingly so as to keep the V/f ratio constant.

A MATLAB code was developed which asks the user to input the Starting Load Torque and Reference speed. The frequency at which the motor should be started so as to operate in the stable zone is calculated. The corresponding voltage is determined. The speed of the rotor is incremented from 0 to the Synchronous speed and the values of the torque were stored. The actual speed of the rotor was ascertained and compared with the reference speed. The resulting difference was taken as the error and original frequency was corrected. The terminal voltage is also modified accordingly, keeping the V/f ratio constant and the process is repeated. The Torque vs Speed graphs were plotted.

The following graph was obtained for Starting Load Torque= 1.5 N.m and Reference Speed= 1000 rpm

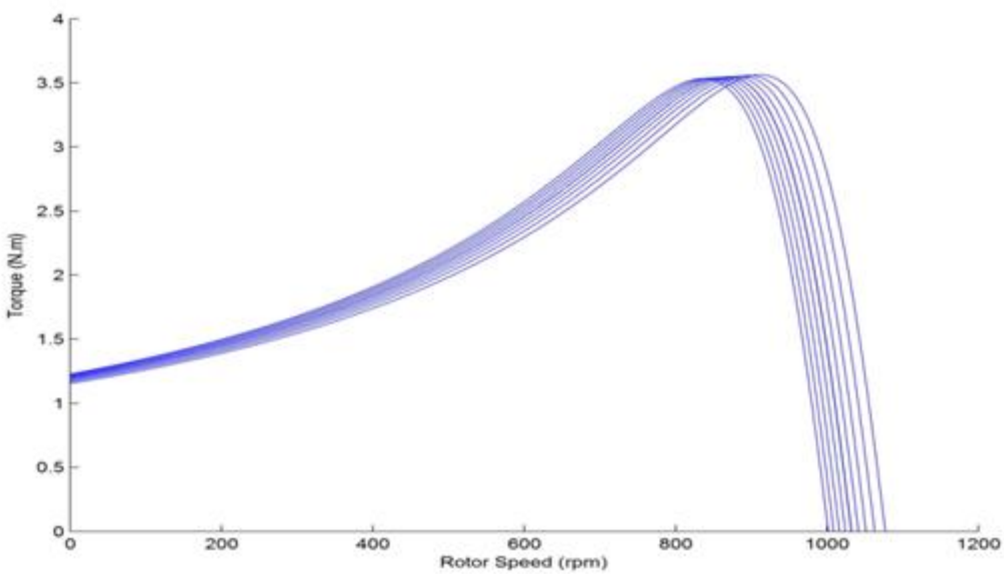

Figure 19: Torque-Speed Characteristics for Tlstarting= 1.5 N.m and Wref= 1000 rpm in Closed-loop V/f Control of Induction Motor

The following Torque-speed curves were obtained for Starting Load Torque of 1 N.m and Reference Speed of 500 rpm

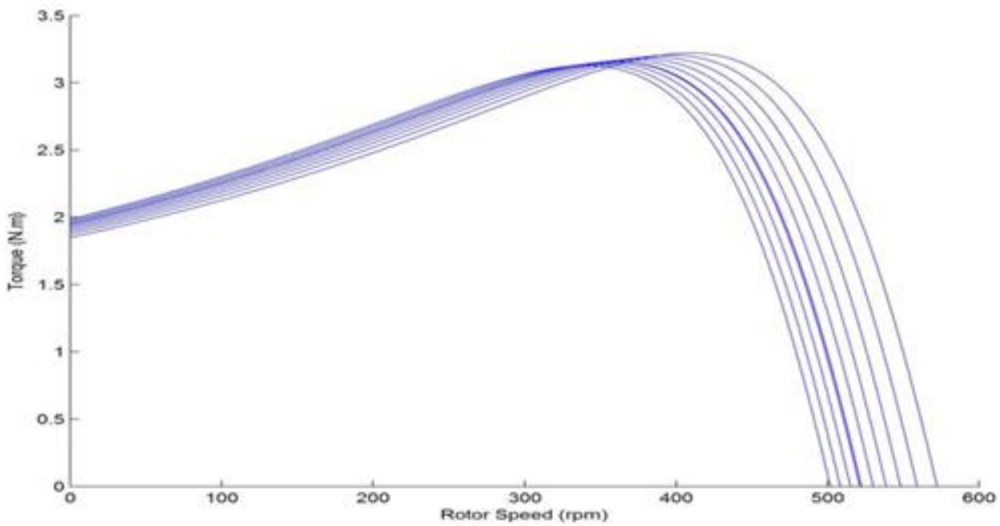

Figure 20: Torque-Speed Characteristics for Tlstarting= 1N.m and Wref= 500 rpm in Closed-loop V/f Control of Induction Motor

Thus here it can be observed that as the frequency is varied, the maximum torque on the rotor remains constant across the speed range. This is the result of keeping the flux constant by maintaining a constant V/f ratio.

Thus the speed of the rotor is measured and compared with the reference speed. This generates an error that is processed by the Proportional Controller which modifies the supply frequency accordingly. As the P Controller feeds the Voltage Source Inverter, the voltage is also varied such that the V/f ratio remains constant. This keeps the flux value constant which in turn ensures a constant maximum torque throughout the speed range. Hence Speed control is achieved in the Induction motor.

CHAPTER 5

Conclusions

5.1 Conclusions

PWM Inverters, both 1-Φ and 3-Φ were modeled and studied. The PWM signals were generated by comparing either a triangular waveform with a sinusoidal waveform using relational operators. These PWM signals were then applied to the gates of forced-commutation devices like IGBT's so as trigger them in a specific sequence to be able to convert the DC supply voltage to an AC output voltage. The DC supply could either be from a battery, a fuel cell, or from a rectifier which receives AC supply from the mains.

A 3-Φ PWM Inverter was also fashioned using the Simulink Library blocks PWM Generator and Universal Bridge. In all cases, successful Inverter action was obtained.

An Induction Motor was run with the help of a PWM Inverter without implementing any kind of speed control mechanisms and the various characteristic curves were obtained. It was observed that there were a lot of transient currents in the stator and rotor at the time of starting and they took some time to settle down to their steady-state values. The lower the stator resistance, the quicker the transients died down and hence, the stator resistance should be kept very low. In an uncontrolled Induction Motor, torque was observed to rise to a maximum value and then settle at the base value, while rotor speed was observed to rise to its rated value and remain constant there.

Open-loop V/f Control was implemented using MATLAB and it was observed that by varying the supply frequency and terminal voltage such that the V/f ratio remains the same, the flux produced by the stator remained constant. As a result, the maximum torque of the motor remained constant across the speed range.

Closed-loop V/f Control used a Proportional Controller to process the error between the actual rotor speed and reference speed and used this to vary the supply frequency. The Voltage Source Inverter varied the magnitude of the Terminal Voltage accordingly so that the V/f ratio remained the same. It was observed that again the maximum torque remained constant across the speed range. Hence, the motor was fully utilized and successful speed control was achieved.

References:

[1]. Dr. P.S. Bimbhra, “Electrical Machinery”, 7th Edition, Khanna Publishers, New Delhi, 2010.

[2]. Gopal K. Dubey, “Fundamentals of Electrical Drives”, 2nd Edition, Narosa Publishing House, New Delhi, 2011.

[3]. M.C. Trigg and C.V. Nayar, “Matlab Simulink Modelling of a Single-Phase Voltage Controlled Voltage Source Inverter”, Dept. of Electrical Engineering, Curtin University of Technology.

[4]. M Harsha Vardhan Reddy and V. Jegathesan, “Open loop V/f Control of Induction Motor based on hybrid PWM with Reduced Torque Ripple”, ICETECT 2011, Karunya University.

[5]. Sharad S. Patil, R.M. Holmukhe, P.S. Chaudhari, “Steady State Analysis of PWM inverter fed Cage Induction Motor Drive”, Department of Electrical Engineering, College of Engineering, Pune, India.

[6]. Neelashetty Kashappa and Ramesh Reddy K., “Performance of Voltage Source Multilevel Inverter-fed Induction Motor Drive using Simulink”, ARPN Journal of Engineering and Applied Sciences, vol. 6, No. 6, June 2011.

[7]. A. E. Fitzgerald, Charles Kingsley, Jr. And Stephan D. Umans, “Electrical Machinery”, McGraw-Hills Publications, Year 2002.

[8]. Scott Wade, Matthew W. Dunnigan, and Barry W. Williams, “Modelling and Simulation of Induction Machine Vector Control with Rotor Resistance Identification”, IEEE transactions on power electronics, vol. 12, no. 3, may 1997.

[9]. “IEEE Standard Test Procedure for Polyphase Induction Motors and Generators”, volume 112, issue 1996 of IEEE, by IEEE Power Engineering Society.